Final Working Paper 4
Transportation Control Measures

Introduction

The objective of Working Paper 4 (WP-4) is to provide an overview of transportation control measures (TCMs) analytical requirements, tools and methodologies. WP-4 includes methodologies for the following project categories:

- Dust Mitigation
- Vehicle Emissions Controls
- Trip Reduction Measures
- Traffic Flow Improvements

Existing Arizona Department of Transportation (ADOT) methodologies were reviewed and compared with current Environmental Protection Agency (EPA) and Federal Highway Administration (FHWA) guidance, as well as national best practices. To ensure all required project types were addressed, ADOT/stakeholder input was solicited in identifying all project types needing analysis. A draft list of project types to be analyzed was provided to ADOT/stakeholders prior to proceeding. The Air Quality Management Guidebook (the Guidebook) will contain all of the methodologies presented in WP-4 in the form of a spreadsheet tool. In addition, the Nogales Case Study will include sample calculations for select project types utilizing MOVES-generated emission rates.

Review of Existing Requirements and Practices

Transportation agencies through their regulatory, operational and purchasing activities have a number of opportunities to initiate programs and policies that may help to mitigate criteria pollutant emissions from a variety of sources. While detailed regional and project-level transportation emission calculations are covered in Working Paper 3: *Air Quality Conformity Procedures*; WP-4 focuses on those additional programs or projects that an agency may need to quantify in order to meet the goals of a State Implementation Plan (SIP), as part of a conformity demonstration, or simply to show a commitment to reducing regional emissions even if the credit is not taken. Such programs and projects are generically referred to as Transportation Control Measures (TCMs).

As stated on the FHWA Website[1]:

Under the Transportation Conformity Rule, Transportation Control Measures (TCMs) are strategies that:

1. *are specifically identified and committed to in State Implementation Plans (SIPs); and*

[1] http://www.fhwa.dot.gov/environment/air_quality/conformity/policy_and_guidance/tcm.cfm

2. *are either listed in Section 108 of the Clean Air Act (CAA) or will reduce transportation-related emissions by reducing vehicle use or improving traffic flow.*

Section 108 of the CAA provides examples of transportation control measures including, but not limited to:

- *improved public transit,*
- *traffic flow improvements and high-occupancy vehicle lanes,*
- *shared ride services,*
- *pedestrian/bicycle facilities, and*
- *flexible work schedules.*

Timely implementation of TCMs criterion must be satisfied before conformity determinations can be made. Consequently, TCMs receive the highest priority for funding under the Congestion Mitigation and Air Quality Improvement (CMAQ) Program.

Many other measures, similar to the TCMs listed in the CAA, are being used throughout the country to manage traffic congestion on streets and highways and to reduce vehicle emissions. Increasingly they are being recognized for their benefits toward improving an area's livability. These TCM type activities may be eligible for CMAQ funding, whether or not they are in approved SIPs, if they are documented to have emission reduction benefits in nonattainment and maintenance areas. These activities have been employed throughout the country for many years and include many travel demand management and transportation system management applications.

Some control measures may be intrinsically incorporated into regional emissions calculations, e.g., through the values and data used to develop mobile source emission budgets or to demonstrate conformity. Common examples of TCMs intrinsic in regional emissions calculations include: the impacts of land use decisions on overall travel, fuel parameters that reflect the impacts of reformulations, and the impacts of federal or state policies aimed at increasing the efficiency of the overall fleet or targeted vehicle populations. Care must be taken to ensure that the impact of TCMs are not double counted; if a project can be addressed in the general development of an emissions inventory rather than separately, that is the preferred approach.

The control measures outlined in this document are commonly used in Arizona and are typically above and beyond the baseline calculations found in most conformity analyses. This is not intended to represent an exhaustive list, as the range of possible control measures is extensive and new and innovative TCMs emerge frequently. It should be noted that the approaches provided are generic in nature and, while sufficient, are not a substitute for detailed analyses.

Analytical Requirements

Control measures are generally held to a higher level of analytical rigor, particularly if their implementation is necessary for an area to demonstrate conformity or if TCMs make a sizable contribution toward meeting local air quality goals. Often these measures are funded by programs such as the CMAQ program and the Diesel Emissions Reduction Act (DERA), which require more rudimentary reporting. When taking credit for a TCM in a SIP or a conformity demonstration these reported values may not be sufficient. The most recent

EPA/FHWA guidance and analysis should always be reviewed to ensure the project/program/policy analyses provided are sufficiently robust for the purposes of being considered as TCMs.[2]

The EPA provides a webpage with a compendium of current guidance, analysis approaches and recent research on TCMs and similar projects/programs.[3]

Consistency and Local Data

There is a significant body of research outlining methods to estimate the impact of various control measures. Under the authority of the CAA, the EPA provides some flexibility in the analysis approaches used, provided they are reasonable and have a sound analytic foundation. When control measures are also determined to be regionally significant projects or programs there are often existing studies that use local data, surveys, modeling, etc. to calculate the transportation or trip-making impacts of the measure. Depending on the availability and design of the regional travel demand model, many control measures that impact trip generation, mode choice, vehicle occupancy and, in some cases, vehicle flow (traffic signal progression, incident response, highway information systems, etc.) may best be investigated using existing analytical tools. Consistency between all planning efforts is desirable. If a particular control measure has been studied locally, and the analysis and data used were developed in a reasonable manner, then those results should be included in the evaluation of air quality impacts. The published generic methods, including those provided below, are generally sketch-level in nature and less rigorous. The interagency consultation process is often helpful in identifying the existence of previous work and ensuring consistency with other reported results (See Working Paper 2: *Interagency Consultation Procedures)*.

Partial Credit, Bundling, and Voluntary Mobile Source Measures

Some TCMs are difficult to quantify, either because the impacts of a particular measure are not well studied, the data needed to calculate the impacts are inadequate or data may need to be synthesized from other sources. The EPA recognizes this issue and, on a case-by-case basis, allows agencies to incorporate uncertainty and still take credit for TCMs. An agency may choose to qualitatively include such TCMs or take partial credit for their impact and can work with their local EPA representatives to identify how partial credits can be used.

Examples of TCMs where taking partial credit may be appropriate are Travel Demand Management (TDM) strategies, such as ride matching, parking management, funding of Transportation Management Associations (TMAs), vanpool programs and other projects designed to shift peak period traffic from Single Occupancy Vehicles (SOVs) to more efficient modes. Historically, the impacts of these programs were believed to overlap and taking credit for them individually could result in over estimating benefits. The benefits of each element of the program are generally calculated independently, however the total benefit was limited to 100 percent of

[2] FHWA provides general guidance and references to recent information via their website: http://www.fhwa.dot.gov/environment/air_quality/conformity/policy_and_guidance/tcm.cfm
[3] http://www.epa.gov/OMS/stateresources/policy/pag_transp.htm

the most impactful project, 50 percent of the next project, and no credit at all for the remaining TCMs in this category.

States can also group individual measures and "bundle" them in a single submission in a SIP. The emissions reductions for each measure in the bundle can be quantified independently and, with an appropriate discount factor for uncertainty applied, the total reductions can be summed together in the SIP submission. After SIP approval, each individual measure will be implemented according to its schedule in the SIP. It is the performance of the entire bundle (the sum of the emissions reductions from all the measures in the bundle) that is considered for SIP evaluation purposes, not the effectiveness of any individual measure.

Bundling is an option for control measures which individually may not have a significant impact or which cannot be reasonably calculated in isolation, but should be analyzed as elements of a broader program or collection of similar projects. In cases where projects might be inter-related, bundling can reduce the chances of double counting and simplify the analysis when data is not readily available.

As an example, retrofitting a single older diesel vehicle with improved emission control technology on its own may be insignificant, however if it is included with several other trucks undergoing similar retrofits the total cumulative impact may warrant consideration and inclusion as a reported benefit. Any correction or discount factor used to account for uncertainty should be developed in conjunction with local EPA representatives. The need to bundle is dependent on the analysis methods used, the data available, and the degree to which the benefits are needed to achieve air quality goals. As with all other TCMs, agencies may choose to pursue programs and not take air quality credit for them and use them solely as a demonstration of a region's commitment to air quality. Additional information on bundling can be found in the EPA guidance.[4]

Voluntary mobile source measures are strategies that are not enforceable against an individual source. An emerging measure is a measure or strategy that does not have the same high level of certainty as traditional measures for quantification purposes.[5] EPA has set a limit on the amount of emission reductions which are permitted to result from the implementation of voluntary measures in a SIP. The limit is set at three percent of the total projected future year emissions reductions required to attain the appropriate National Ambient Air Quality Standard (NAAQS). However, the total amount of emissions reductions from voluntary measures shall also not exceed 3 percent of the statutory requirements of the CAA with respect to any SIP submittal to demonstrate progress towards attainment or maintaining compliance with the NAAQS.

States that use voluntary mobile source measures must commit to evaluating these measures. These enforceable commitments would describe how the agency plans to evaluate program implementation and report on program results in terms of actual emissions reductions. Program evaluation provisions must be

[4] http://www.epa.gov/ttn/oarpg/t1/memoranda/10885guideibminsip.pdf
[5] United States Environmental Protection Agency. Incorporating Bundled Measures in a State Implementation plan (SIP). August 2005

accompanied by procedures designed to compare projected emissions reductions with actual emissions reductions achieved. The timing of the evaluations must be specified in the SIP submittal.[6]

Analytical Tools

EPA MOVES Model

The transition from EPA's MOBILE model to the Motor Vehicle Emission Simulator (MOVES) model impacted the way in which TCMs are being analyzed because the basic concepts on how emission rates are developed changed significantly. The generic emission factors that can be found in previous guidance documents were developed using MOBILE and must be updated using MOVES. More fundamentally, MOVES changes the way projects that improve vehicle flow are perceived and quantified. MOBILE was unable to accurately reflect the drive cycle for vehicles in unstable traffic flow such as in highway congestion or at traffic signals. Projects that addressed these vehicle delays were often analyzed as a reduction in idling emissions. MOVES is capable of more directly analyzing these types of speed profile changes, however guidance and research are limited and continue to evolve. Agencies may wish to acknowledge, but not take credit for the following types of projects, in the interim:

- Intelligent Transportation Systems (ITS) designed to reduced recurring and accident/incident roadway delay
- Service patrols
- Traffic signal improvement projects
- Roundabouts

Alternately, a number of existing methods exist which calculate the impacts of these projects as a reduction in vehicle idling. While MOVES can generate emission rates for queuing conditions, this is likely a very conservative estimate of the project benefits. Some MOVES pre and post processors, as well as regional travel demand models, already include methods to estimate the emission benefits of these and similar projects. If those capabilities exist, it is likely that employing those modules/models is the most appropriate way to handle these project types.

AP-42

In much of the US, air quality issues are primarily the result of chemical processes and combustion sources from industrial, commercial and personal activities. As a result, research and guidance at the national level has focused more on control measures that address ozone and $PM_{2.5}$ emissions. In Arizona the climate conditions and soil composition make airborne dust and PM_{10} important issues. This fugitive dust is both naturally occurring, as well as the result of activities such as construction grading and re-entrained roadway dust. Methods to reduce this fugitive dust have traditionally focused solely on PM_{10} impacts, although by definition PM_{10} contains varying degrees of $PM_{2.5}$ as well.

[6] United States Environmental Protection Agency. *Memorandum: Guidance on Incorporating Voluntary Mobile Source Emission Reduction Programs in State Implementation Plans (SIPs)* dated 10/24/1997

The EPA guidance "AP 42, Compilation of Air Pollutant Emission Factors" commonly referred to as "AP-42" or "AP-42 methods" is the definitive source for analysis techniques used to quantify the impacts of control measures for re-entrained dust as highlighted below. In particular "Chapter 13-Other Sources" covers baseline emissions and methods to calculate the benefits of several control measures.

Throughout AP-42 all emission reductions are calculated using the following formulation:

E = A x EF x (1-ER/100)

Where:
E = Emissions
A = Activity rate (Generally VMT)
EF = Emission factor
ER = Overall emission reduction efficiency (%)

The Maricopa Association of Governments (MAG) *Methodologies for Evaluating Congestion Mitigation and Air Quality Improvement Projects*[7] also provides a number of useful analytical approaches. While CMAQ analysis in general does not need to be as in depth as the analysis typical of a control measure, the MAG CMAQ methodologies are notable for their completeness and have been used by other agencies in evaluating TCM benefits.

Measures to control PM_{10} from fugitive sources generally have the co-benefit of reducing $PM_{2.5}$. EPA has estimated that approximately 25 percent of PM_{10} fugitive dust by weight can be attributed to $PM_{2.5}$[8]; while the Western Regional Air Partnership (WRAP) estimates this at approximately 21 percent by weight. Benefits can be estimated by first determining PM_{10} reductions using either AP-42 or another methodology, and then applying one of the recommended percentages (21 percent or 25 percent) to calculate the corresponding $PM_{2.5}$ emissions reduced. Care must be taken when using this approach as $PM_{2.5}$ may not necessarily be reduced to the same degree as PM_{10}. For example, while efforts to reduce the amount of grading at a construction site would impact PM_{10} and $PM_{2.5}$ in a similar ratio, this assumption may not be appropriate when analyzing road sweepers that are not rated for $PM_{2.5}$.

The fugitive dust sections of AP-42 do not provide estimates for other criteria pollutants (VOC, NO_X, etc.) as they are not present in significant amounts in re-entrained, airborne dust.

Control Measure Analysis: Methods and Examples

The following section contains suggested analytical methods for various control measures that have historically been used in the state of Arizona, as well as some additional project types that may be of use to agencies in the development of SIPs and conformity demonstrations. The focus of these measures is PM_{10}

[7] http://www.azmag.gov/Documents/CMAQ_2011-04-05_Final-CMAQ-Methodologies_3-31-2011.pdf
[8] United States Environmental Protection Agency, *AP-42, Background Documentation, Figure 13.2.1-2*, January 2011.

emission reductions and accompanying $PM_{2.5}$ emission reductions, primarily through fugitive dust reductions. In cases where projects would also have accompanying ozone or $PM_{2.5}$ precursor emission reductions, these are provided as well.

Methods to calculate the emission benefits of common transportation and related control measures are continually evolving as new research and guidance become available. Additionally, there are often multiple ways in which any given project might be analyzed. This document does not represent an endorsement of particular methodologies, but has been designed as a resource containing several samples. Agencies are encouraged to use any existing, detailed analyses that may be available rather than applying more generic approaches.

Agencies should always check for updated guidance and research from EPA, FHWA and other sources. The recent Moving Ahead for Progress in the 21st Century (MAP-21) transportation legislation is funding several concurrent studies on measuring the effectiveness of projects and programs, some of which include common TCMs. In particular the CMAQ section of the bill funds two studies, one evaluating the existing success of the program and a second, separate effort to develop consistent metrics and methods going forward. It is expected that the recommended analysis approaches for many control measures will benefit from this work.

List of Control Measures Reviewed

Dust Mitigation Projects

- Unpaved Roads Surface Treatments
- Unpaved Roads Surface Improvement
- Road/Alleyway Paving
- Paving Shoulder/Gutter/Curb
- Paving Bicycle Trails
- Certified Street Sweepers

Vehicle Emissions Controls

- Non-Road Diesel Retrofits
- Retrofits, Clean Diesel and Alternative Fuel Vehicles
- Truck Stop Electrification/Auxiliary Power Units

Additional Significant Control Measures

- Regional Diesel Anti-idling Regulations
- Fuel Measures - Inspection and Maintenance Programs

Trip Reduction Measures

- Bicycle and Pedestrian Facilities
- New Bus Service

- Park and Ride
- Trip Reduction Programs/Measures

Traffic Flow Improvements

- Traffic Sign Coordination & Intelligent Transportation Systems
- Land Ports of Entry (Border Crossings) Operational Improvements

Dust Mitigation Projects

Unpaved Roads Surface Treatments

All roads release dust (PM_{10} and $PM_{2.5}$) when traveled on, and depending on the soil and climate conditions this tends to be far more pronounced on unpaved roads. Rainfall and moisture play a significant role in the amount of dust generated per vehicle passing, and the dry conditions in much of Arizona make air quality issues due to re-entrained road dust prevalent in the state. Surface treatments are a lower-cost way to help reduce the dust production on unpaved roads on a temporary basis. A number of products are available and are generally sprayed onto the roadway surface or mixed with aggregate and then reapplied as the running surface on the roadbed.

ADOT tested two surface treatments for unpaved roads as part of the project entitled "Identification of Emissions Sources for Pinal County". Field measurements of PM_{10} emission rates were made on two different state routes, SR88 and SR288. The segment of SR88 between mile point 220.1 and mile point 227.5 was treated with Envirotac II Acrylic copolymer at a rate of 1 gallon per 36 square feet; after 5 months the PM_{10} emissions were reduced by a factor of 5. The segment of SR288 between mile points 274.7 and 280.5 was treated by milling 6 inches of the base material that was treated with a 1:1 ratio of SS1 followed by an application of CRS II Emulsified liquid at a rate of 0.5 gallons per square yard and then 28 pounds per square yard of 3/8 inch chips; after 1 year PM_{10} emissions were reduced by a factor of 60. This study also looked at typical cost effectiveness results from other dust palliative applications as illustrated by Table 4-1.

Table 4-1: Dust Control Surface Treatments Methods Costs and Effectiveness

Dust Control Category	Specific Product	Control Cost ($/Mile of Roadway Treated)	Control Effectiveness Range	Control Duration
Moisture Increase	Watering	$31	0% - 50%*	0.5-1 Hours
	Calcium Chloride	$18,000	0% - 70%**	6 Months
Particle Agglomeration	EK-35	$16,000	0% - 99%***	1 Year
	Lignosulfonate	$12,000	0% - 90%*	2 Months
	Soil Sement	$18,000	0% - 84%****	1 Year
Soil Coverage	Gravel	$16,000	0% - 30%*	1 Year
	Asphalt Paving	$311,000	90% - 99%	20 Years
* Orlemann, 1983				
** Morgan, 2005				
*** MRI, 2002				
****California ARB, 2002				

Given the wide range of effectiveness for dust palliatives, ADOT intends on adopting dust control methodologies from the Idaho Department of Transportation, which lists the emissions reduction control efficiencies for water at 50 percent and chemical stabilizers at 70 percent. ADOT is also reviewing the appropriateness of the emissions factors assumption for unpaved roads and construction fugitive dust emissions as these factors may change in the future.

Example: The City of Nogales will apply chemical dust palliatives twice a year to stabilize 4 miles of a rural unpaved road with an average daily traffic (ADT) of 200. The product specifications state that one application will be effective for 180 days and the City is purchasing a one year supply of dust palliative. Figure 4-1 illustrates how the emissions benefits are calculated. This project produces an annual PM_{10} emissions reduction of 142,591.68 kg/year and an adjustment factor of 0.25 is used to estimate a $PM_{2.5}$ emissions reduction of 35,647.92 kg/year.

Figure 4-1: Sample of Dust Suppression Calculation

	Emissions Factor (kg/mile)
Urban Unpaved	0.36
Rural Unpaved	0.7073
Topsoil Removal	9
Earthmoving	1.95
Truck Haulage	4.54

	Control Efficiency		Number of Days
Water	50%		N/A
Chemical Stabilizers	70%		180

Daily Emissions Reductions

Road Name	Emissions Factor (kg/mile)	x	Control Efficiency	x	Average Daily Traffic	x	Length of Segment (miles)	=	Daily Emissions Reductions (kg/day)
Example	0.7073	x	0.70	x	200	x	4	=	396.09

Number of Days with Emissions Reductions

Number of Days Effective per Application	x	Number of Applications per Year	=	Number of Days with Emissions Reductions (days/year)
180	x	2	=	360

Annual Emissions Reductions

Daily Emissions Reductions (kg/day)	x	Number of Days with Emissions Reductions (days/year)	=	Annual PM_{10} Emissions Reductions (kg/year)		PM2.5 Conversion Factor		Annual PM2.5 Emissions Reductions (kg/year)
396.09	x	360	=	142,591.68	x	0.25	=	35,647.92

Unpaved Roads Surface Improvement

Unlike the temporary surface treatments described above, surface improvements are relatively permanent and do not require periodic retreatment. The most obvious surface improvement is paving an unpaved road. This option is comparatively high-cost and is most applicable to relatively short stretches of unpaved road with at least several hundred ADT. Furthermore, if the newly paved road is located near unpaved areas or is used to transport material, it is essential that the control plan address routine cleaning of the newly paved road surface. The control efficiencies achievable by paving can be estimated by comparing emission factors for unpaved and paved road conditions.

Other surface improvement methods involve covering the road surface with another material that has lower silt content. Examples include placing gravel or slag on a dirt road. The control efficiency can be estimated by comparing the emission factors obtained using the silt content before and after improvement. The silt content of the road surface should be determined after 3 to 6 months rather than immediately following placement. Control plans should address regular maintenance practices, such as grading, to retain larger aggregate on the traveled portion of the road. The paving of unpaved roads and unpaved parking areas can result in a control efficiency of 99 percent based on the comparison of paved road and unpaved road emissions factors.

Calculations for Paving Unpaved Roads or Alleys:

Daily Emission Reductions = (BEF – AEF) * Miles * 0.93 * ADT * 1 /1000 (kg/day)

Where:

BEF =	The PM_{10} emission factor (g/mi) for vehicles traveling on unpaved roads or alleys
AEF =	The PM_{10} emission factor (g/mi) for vehicles traveling on paved roads or alleys
	The MAG CMAQ guidance recommends 658.69 g/mi for BEF-AEF (660.16 g/mi– 1.47 g/mi)
Miles =	The length of the project (in centerline miles)
ADT =	The average weekday traffic on the unpaved road or alley
0.93 =	The factor to convert from weekday to annual average daily traffic on arterials.

Example: The City of Nogales plans to pave a 2 mile section of unpaved road that accesses an existing paved road. This road has an annual VMT of 200,000 with an ADT of 550. The City will also install curb and gutter on both sides of the road with paved shoulders; the paving has an expected lifecycle of 15 years. The calculations are illustrated in Figure 4-2.

Figure 4-2: Sample Paving Unpaved Road or Alley Calculation

Difference in Emissions Factors

	Emissions Factor Unpaved (g/mile)	-	Emissions Factor Paved (g/mile)	=	Difference in Emissions Factors (g/mile)
Road	660.16	-	1.47	=	658.69
Alley	417.45	-	1.47	=	415.98

Daily Emissions Reductions = (BEF – AEF) x Miles x 0.93 x ADT x 1 /1000 (Kg/day)

Road Name	Difference in Emissions Factors (g/mile)	x	Length of Segment (miles)	x	Average Daily Traffic	=	$PM_{10}/PM_{2.5}$ Emissions Reductions (kg/day)
Example	658.69	x	2	x	550	=	673.84
Example	658.69	x	2	x	550	=	168.46

Annual PM_{10} Emissions Reductions

Total Daily Emissions Reductions (kg/day)	x	Number of Days per Year (days/year)	=	Annual Emissions Reductions (kg/year)
673.84	x	365	=	245,951.55

Annual $PM_{2.5}$ Emissions Reductions

Total Daily Emissions Reductions (kg/day)	x	Number of Days per Year (days/year)	=	Annual Emissions Reductions (kg/year)
168.46	x	365	=	61,487.89

Paving Shoulders and/or Curbs and Gutters:

Re-entrained dust emanating from paved roads is in part dependent on whether the road shoulder is paved. Paving shoulders and gutters reduces the generation of dust, particularly from vehicle excursion onto unpaved shoulders. It is recommended that roads with an ADT of 500 to 3,000 should have an average shoulder width of at least four feet. Roads with an ADT that is greater than 3,000 should have an average shoulder width of at least eight feet. The reduction of road dust associated with paved shoulders depends on other site-specific variables including silt loading.

The following approach was taken from the MAG *Methodologies for Evaluating Congestion Mitigation and Air Quality Improvement Projects* and provides a basic framework for analyzing these project types.

Calculations for Paving Unpaved Shoulders and/or Providing Curbs and Gutters (C&G):

Daily Emission Reductions = Miles * ADT * 0.93 * RF * 1 /1000 (kg/day)

Where:

Miles = The length of the project (in centerline miles)

ADT = The average weekday traffic on the road adjacent to the unpaved shoulders
0.93 = The factor to convert from weekday to annual average daily traffic
RF = Emission reduction factor in grams per VMT for PM_{10}

Low volume arterials (<10,000 ADT)

- 0.76 g/VMT, if paving shoulders and providing C&G on both sides of the road
- 0.57 g/VMT, if paving shoulders on both sides of the road without C&G
- 0.38 g/VMT, if paving shoulder and providing C&G on one side of the road
- 0.29 g/VMT, if paving shoulder on one side of the road without C&G
- 0.19 g/VMT, if providing C&G on both sides of a road with paved shoulders
- 0.10 g/VMT, if providing C&G on one side of a road with a paved shoulder

High volume arterials (> 10,000 ADT)

- 0.53 g/VMT, if paving shoulders and providing C&G on both sides of the road
- 0.40 g/VMT, if paving shoulders on both sides of the road without C&G
- 0.27 g/VMT, if paving shoulder and providing C&G on one side of the road
- 0.20 g/VMT, if paving shoulder on one side of the road without C&G
- 0.14 g/VMT, if providing C&G on both sides of a road with paved shoulders
- 0.07 g/VMT, if providing C&G on one side of a road with a paved shoulder

Example: A two-mile road paving project will add shoulders, curb and gutter to an existing paved roadway. The following values have been provided:

- A reduction Factor (RF) of 0.19 g/mi for a low volume road
- An ADT of 550
- There are 365 days in the analysis year (no reduction for holidays or weekends)
- The lifespan of the project is estimated at 15 years

The calculations are summarized in Figure 4-3 below. Emissions reductions for $PM_{2.5}$ were calculated by assuming that 25 percent of total PM_{10} can be attributed to $PM_{2.5}$. The example produces a PM_{10} emissions reduction of 70.95 kg/year and a $PM_{2.5}$ emissions reduction of 17.74 kg/year.

Figure 4-3: Sample Shoulder and/or Curb & Gutter Paving Calculation

Reduction Factor (RF) (g/vmt)

	Low volume arterials (<10,000 ADT)	High Volume arterials (>=10,000 ADT)
If paving shoulders and providing C&G on both sides of the road	0.76	0.53
If paving shoulders on both sides of the road without C&G	0.57	0.4
If paving shoulders and providing C&G on one side of the road	0.38	0.27
If paving shoulders on one side of the road without G&G	0.29	0.2
If providing C&G on both sides of a road with paved shoulders	0.19	0.14
If providing C&G on one side of a road with paved shoulders	0.1	0.07

Daily Emissions Reductions = miles x ADT x 0.93 x RF x 1/1000 x 0.25 (PM_{10} to $PM_{2.5}$) (kg/day)

Project Name	Length of Segment (miles)	x	Average Daily Traffic	x	RF	=	PM_{10}/$PM_{2.5}$ Emissions Reductions (kg/day)
Example	2	x	550	x	0.19	=	0.19437
Example	2	x	550	x	0.19	=	0.0485925

PM_{10} Annual Emissions Reductions

Total Daily Emissions Reductions (kg/day)	x	Number of Days per year (days/year)	=	Annual Emissions Reductions (kg/year)
0.19437	x	365	=	70.94505

$PM_{2.5}$ Annual Emissions Reductions

Total Daily Emissions Reductions (kg/day)	x	Number of Days per year (days/year)	=	Annual Emissions Reductions (kg/year)
0.0485925	x	365	=	17.7362625

Paved Road Baseline Emissions

For some projects, it is necessary to calculate the baseline emissions for a paved roadway and then use this as the starting point for further calculations. Base emissions on the roadway from re-entrained dust are illustrated in Figure 4- 4 and are calculated as follows:

Emissions Factor is $E = [k\,(sL)^{0.91} \times (W)^{1.02}]\,(1 - P/4N)$
Annual Emissions Reduction $= \text{Roadway } VMT_{Annual} * E$

Where:

E = Annual or other long-term average emission factor in the same units as k
k = Particle size multiplier for particle size range and units of interest (PM_{10} = 1.0 g/VMT and $PM_{2.5}$ = 0.25 g/VMT)
sL = Road surface silt loading = 0.105 g/m^2 (ADEQ Nogales PM_{10} SIP)
W = Average weight (tons) of the vehicles traveling on the road = 3 tons
P = Number of "wet" days with at least 0.254 mm (0.01 in) of precipitation during the averaging period
AP-42 = 60 days/365 days per year in the region containing Nogales
ADEQ Nogales Nonattainment Plan = 45 days/365 days per year
N = Number of days in the averaging period (e.g., 365 for annual)

Figure 4- 4: Sample Paved Road Baseline Emissions Calculation

Particle Size Multiplier (k) (g/VMT)	Road Surface Silt Loading (sL) (g/m^2)	Average Weight of Vehicles (W) (ton)	Number of Wet Days (P) (>=0.254mm)	Number of Days in Averaging Period	$PM_{10}/PM_{2.5}$ Emission Factor (E_{ext})
1	0.105	3	45	365	0.382251788
0.25	0.105	3	45	365	0.095562947

Annual PM_{10} Emissions Reduction: Roadway VMT_{Annual} x E_{ext}

Road Name	RoadwayVMT_{Annual}	x	Emissions Factor (E_{ext})	=	Annual Emissions Reduction (kg/year)
Example	200,000	x	0.382251788	=	76.45035769
				Total Daily Emissions	76.45035769

Annual $PM_{2.5}$ Emissions Reduction: Roadway VMT_{Annual} x E_{ext}

Road Name	RoadwayVMT_{Annual}	x	Emissions Factor (E_{ext})	=	Annual Emissions Reduction (kg/year)
Example	200,000	x	0.095562947	=	19.11258942
				Total Daily Emissions	19.11258942

Bicycle and Pedestrian Projects (Re-entrained PM only):

The methodology for calculating emission reductions from a bike or pedestrian project assumes that a dirt surface will be paved requiring the use of the Baseline Paved Road Calculation (see Figure 4- 4 above.) The project must demonstrate there will be a reduction in auto travel to be eligible for CMAQ funding. This simplified approach requires a separate analysis to estimate the bicycle trips generated by the project.

Example: The City of Nogales wishes to provide a bicycle path along an arterial roadway; it is assumed that 15 bikes a day will use this path. The calculations and assumptions used are shown in Figure 4-5 below.

Figure 4-5: Bicycle and Pedestrian Calculation Sheet

Single Occupancy Vehicle (SOV) Miles Replaced

Expected Average Daily Bike Traffic	/	Average Auto Occupancy*	x	Average Trip Length (miles/trip)**	=	Daily SOV Miles Replaced (miles/day)
15	/	1.4	x	3	=	32.14285714

*NOTE: For Average vehicle occupancy use local data, or 1.4 as default.

**NOTE: For Average Trip Length use local data, 3 is conservative

Pollutant	Emissions Factor (kg/mile)
PM_{10} Paved	0.382251788
$PM_{2.5}$ Paved	0.095562947

Daily Emissions Reductions (SOV Vehicle Emissions Saved)

Pollutant	Daily SOV Miles Replaced (miles/day)	x	Emissions Factor	=	Daily Emissions Reductions (kg/day)
PM_{10}	32.14285714	x	0.382251788	=	12.28666461
$PM_{2.5}$	32.14285714	x	0.095562947	=	3.071666154

Annual Emissions Reductions

Pollutant	Daily Emissions Reductions (kg/day)	x	Number of Days per Year (days/year)	=	Annual Emissions Reductions (kg/year)
PM_{10}	12.28666461	x	365	=	4,484.63
$PM_{2.5}$	3.071666154	x	365	=	1,121.16

Certified Road Street Sweepers

Paved road dust is fugitive dust that is deposited on a paved roadway and then re-entrained into the air by passing vehicles. Dust is deposited on the roadway by being blown from disturbed areas, tracked from unpaved shoulders or vehicles traveling on connecting unpaved roads, stirred up from unpaved shoulders by wind currents created from traffic movement, spilled by haul trucks, and deposited by water runoff or erosion. Vehicles cause dust from paved and unpaved roads to be re-entrained or re-suspended in the atmosphere. The forces created by the rolling wheels of vehicles remove fine particles from the road bed and also pulverize aggregates lying on the surface. Emissions of paved road dust are generally proportional to vehicle miles traveled. Re-entrained road dust emission rates are primarily affected by the silt loading on the road and amount of vehicle travel. Emission rates are lower per mile traveled on more trafficked roads.

According to the WRAP Fugitive Dust Handbook, an 86 percent sweeping efficiency and a 14-day frequency can result in a PM_{10} control efficiency of 16 percent for local streets and a control efficiency of 26 percent for arterial/collector streets.

Table 4-2 illustrates the anticipated emissions effectiveness of paved road dust reduction control measures based on research compiled within the AP-42 background documentation. It is important to note that not all sweepers are certified to reduce $PM_{2.5}$, which is necessary if the quoted reductions are to be achieved[9].

Table 4-2: Particulate Matter (PM_{10} and $PM_{2.5}$) Emissions Effectiveness of Paved Road Dust Reduction Control Measures

Sweeper Technology	Percent Effectiveness
Sweeping Alone	**16-50 Percent**
Water Flushing	**30-70 Percent**
Sweeping and Water Flushing	**35-90 Percent**

Environment Canada has verified the effectiveness of certain sweepers as being equally capable (on a percent reduction basis) in reducing fugitive $PM_{2.5}$ and PM_{10} [10] without special considerations. By extension, the PM_{10} reduction effectiveness percentages in Table 4-2 may be extended to $PM_{2.5}$ emissions reductions with some confidence.

Example: A county is requesting CMAQ funding to purchase a street sweeper. The county has four roads with a total of sixty-five miles that will be swept twice a month. The County provided a listing of each road name, length, and ADT. The control efficiency of this sweeper was determined to be 30 percent due to the limited sweeping schedule and the type of sweeper that was purchased (not on the SCAQMD certified PM_{10} efficient street sweeper list). It is expected that this sweeper will be used for 18 years. Figure 4-6 outlines the emission reduction calculations for PM_{10} to $PM_{2.5}$. This example produces a PM_{10} emission reduction of 115,381.30 kg/year and a $PM_{2.5}$ emission reduction of 28,845.30 kg/year.

[9] http://www.aqmd.gov/rules/doc/r1186/r1186_equip.pdf lists California's South Coast Air Quality Air Quality Management District (SCAQMD) Certified Street Sweepers under SCAQMD Rule 1186 (August 30, 2012).

[10] http://www.tymco.com/environment/dustless-sweeping.htm. Note that the Environmental Technology Verification (ETV) is funded by the government agency Environment Canada and is considered an independent testing resource.

Figure 4-6: Paved Road Sweeping Calculation Sheet

Emission Factor	
0.382251788	PM_{10}
0.095562947	$PM_{2.5}$

Control Measure	
Sweeping Alone	16 - 50%
Flusher Truck	30 - 70%
Combined	35 - 90%

PM_{10} Emissions Reductions Over Entire Network

Road Name	Emissions Factor (kg/mile)	x	Control Efficiency	x	Average Daily Traffic	x	Lane Miles to be Cleaned (miles)	=	PM_{10} Emissions Reductions (kg/day)
Road 1	0.000382252	x	30	x	100,000	x	20.00	=	22,935.12
Road 2	0.000382252	x	30	x	75,000	x	20.00	=	17,201.34
Road 3	0.000382252	x	30	x	120,000	x	10.00	=	13,761.07
Road 4	0.000382252	x	30	x	50,000	x	15.00	=	8,600.67
					Emissions Reductions Over Entire Network				62,498.20
					Total Lane Miles to Be Cleaned		65.00		

$PM_{2.5}$ Emissions Reductions Over Entire Network

Road Name	Emissions Factor (kg/mile)	x	Control Efficiency	x	Average Daily Traffic	x	Lane Miles to be Cleaned (miles)	=	$PM_{2.5}$ Emissions Reductions (kg/day)
Road 1	9.55629E-05	x	30	x	100,000	x	20.00	=	5,733.77
Road 2	9.55629E-05	x	30	x	75,000	x	20.00	=	4,300.33
Road 3	9.55629E-05	x	30	x	120,000	x	10.00	=	3,440.26
Road 4	9.55629E-05	x	30	x	50,000	x	15.00	=	2,150.17
					Emissions Reductions Over Entire Network				15,624.53
					Total Lane Miles to Be Cleaned		65.00		

Percent of Total Lane Miles to be Cleaned per Day

Lane Miles Cleaned per Day	÷	Total Lane Miles to Be Cleaned	=	Percent of Total Lane Miles to be Cleaned per Day
5	÷	65.00	=	8%

Daily Emission Reductions

Emissions Reductions Over Entire Network (kg)	x	Percent of Total Lane Miles to be Cleaned per Day	=	Daily PM_{10} Emissions Reductions (kg/day)
62,498.20	x	8%	=	4,807.55
Emissions Reductions Over Entire Network (kg)	**x**	**Percent of Total Lane Miles to be Cleaned per Day**	**=**	**Daily $PM_{2.5}$ Emissions Reductions (kg/day)**
15,624.53	x	8%	=	1,201.89

Annual Emissions Reductions

Daily Emissions Reductions (kg/day)	x	Number of Days per Year that Roads are Cleaned (days/year)	=	Annual PM_{10} Emissions Reductions (kg/year)
4,807.55	x	24	=	115,381.30
Daily Emissions Reductions (kg/day)	**x**	**Number of Days per Year that Roads are Cleaned (days/year)**	**=**	**Annual $PM_{2.5}$ Emissions Reductions (kg/year)**
1,201.89	x	24	=	28,845.29

Vehicle Control Measures

Non-Road Diesel Retrofits

Non-road diesel equipment, primarily construction equipment, has only been subject to significant emission reduction levels since 2012 when Ultra Low Sulfur Diesel (ULSD) fuel became required for all off-road vehicles. Construction equipment tends to have long lifespans and, as a result, these retrofits may have a longer-term impact than retrofits to on-road vehicles, which have been subject to stricter emission standards starting with the 2008 model year.

While many technologies to reduce PM emissions from diesel engines result in co-benefits (generally reducing hydrocarbon (HC) emissions and occasionally NO_X as well), the retrofit verification process does not necessarily certify reductions for any pollutant other than PM. Most retrofit programs allow for CARB-verified technologies to be used which, by definition, have no verified NO_X reductions. Given that retrofit technologies are not necessarily certified for reductions in precursors to ozone, taking credit for potential HC or NO_X reductions is not possible at this time.

Construction Equipment Related Emissions/Exhaust

In 2009 ADOT conducted a yearlong study on emissions impacts of widening SR92 in Sierra Vista[11]. One of the goals of this study was to determine the impact of a road construction project on $PM_{2.5}$ emissions. A summary of the emission results from this study is in Table 4-3. While a large portion of $PM_{2.5}$ is generated from exhaust from diesel engines, in the absence of strict controls, fugitive dust still contributes a larger percentage of emissions for a road construction project.

ADOT is still researching ways to estimate road construction dust and emissions factors for potential CMAQ projects. The Sierra Vista study estimated the construction activity for a 4-mile road widening project that added 2 travel lanes and a center auxiliary lane. This project produced 29.0 kg of PM_{10}, 6.0 kg of $PM_{2.5}$, and 30.0 kg of NO_X; assumptions could be made that similar types of projects would produce similar emissions. In addition to measuring emissions from a typical road construction project, this study looked at existing mitigation controls for $PM_{2.5}$ including retrofitting construction equipment.

Table 4-3: Emissions from SR92 Road Widening Year 2009

Emissions Source	PM_{10} (kg)	$PM_{2.5}$ (kg)	Total PM (kg)
Construction Equipment Exhaust	553 (8%)	537 (37%)	1,090 (13%)
Fugitive Dust	6,490 (92%)	924 (63%)	7,414 (87%)

Construction equipment inventories at a given site can be difficult to obtain, if they exist at all. This highlights the difficulty in calculating the benefits of programs to address the emissions from these vehicles. Anecdotally, the longevity of the equipment, along with the fact that tighter controls were only mandated with the 2012 model year, would indicate some potential for declines in emissions from this source.

[11] http://ntl.bts.gov/lib/37000/37800/37836/2010-STI-ADOT-Construction-Study-Final-Report-10-25-10.pdf

In the absence of good local data, the generic emissions rates generated from national databases may offer the best opportunity to calculate the impacts of these activities. Both the National Mobile Inventory Model (NMIM)[12] and the NONROAD[13] model have the ability to generate estimates of total emissions by industry, fuel, month, and vehicle type at the county level. The total emissions for a given category of equipment can be divided by the vehicle population to yield the average emissions per vehicle. As the population includes a combination of newer, older and retrofitted equipment, the average emission rate is a conservative value. Using retrofit emission reduction percentages found in the EPA[14] or CARB[15] lists of certified technologies, the reduction in emissions can be calculated by multiplying the total emissions for the period in question by the reduction rates. Additional correction factors may be applied to account for unknowns such as the percent of time the retrofitted equipment might be operating within a given non-attainment area. Such reduction factors should be developed in conjunction with local EPA representatives.

Example: ADOT has developed a program to encourage contractors to use retrofitted construction equipment on state contracts through financing the installation of Best Available Retrofit Technologies (BART) with a threshold goal of 85 percent reduction in $PM_{2.5}$ emissions. With the funding available the agency estimated 40 vehicles could be retrofitted through this program. As the program focused solely on $PM_{2.5}$ reductions, no other co-benefits (i.e. reductions in other emissions) were accredited to this TCM.

The EPA NONROAD 2008a model was used for this analysis. NONROAD2008a is a major update of the NONROAD model and it supersedes all previous versions of this model, most recently NONROAD2005. It calculates past, present and future emissions inventories (i.e., tons of pollutant) for all non-road equipment categories except commercial marine, locomotives and aircraft. The model estimates exhaust and evaporative hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_X), particulate matter (PM), sulfur dioxide (SO_2), and carbon dioxide (CO_2). The user may select a specific geographic area (i.e., national, state or county) and time period (i.e., annual, monthly, seasonal or daily) for analysis. Note the emissions rates provided are only samples and not specific to Arizona; any analysis would require application of the NONROAD model for a specific location and date. These calculations are illustrated in Figure 4-7.

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[12] http://www.epa.gov/otaq/nmim.htm
[13] http://www.epa.gov/otaq/nonrdmdl.htm
[14] http://www.epa.gov/cleandiesel/verification/verif-list.htm
[15] http://www.arb.ca.gov/msprog/ordiesel/vdecs.htm#currentdevices

Figure 4-7: Sample Calculations of the Benefits of Construction Retrofit program

Sample Emissions for Construction Source Types - EPA NONROAD Model										
HP Range	**Population**	**Total Fleet Summer Day Emission (Tons)**				**Total Fleet Annual Emission (Tons)**				
		VOC	**NOX**	**CO**	**PM2.5**	**VOC**	**NOX**	**CO**	**PM2.5**	**SO2**
100 < HP <= 175	6,997	0.56	5.21	2.36	0.54	149.85	1,401.49	634.82	144.98	46.12
175 < HP <= 300	3,488	0.38	4.60	1.48	0.36	101.66	1,236.97	397.48	97.23	48.08
175 < HP <= 600	1,932	0.35	5.63	2.18	0.37	94.54	1,513.92	586.30	98.66	47.90
600 < HP <= 750	401	0.12	2.03	1.11	0.14	33.34	546.60	298.53	38.49	18.48
750 < HP <= 1,000	111	0.07	1.06	0.36	0.06	20.03	284.89	96.77	15.74	6.95
1,000 < HP <= 1,200	60	0.05	0.71	0.24	0.04	13.19	190.08	64.36	10.38	4.60
1,200 < HP <= 2,000	91	0.14	1.98	0.69	0.11	37.62	532.99	185.93	30.49	13.82
2,000 < HP <= 3,000	13	0.03	0.45	0.16	0.03	8.53	121.59	41.87	7.05	3.36
Total:	**13,093**	**1.70**	**21.67**	**8.58**	**1.65**	458.76	5,828.53	2,306.06	443.02	189.31
Emissions/Vehicle:		**0.0001**	**0.0017**	**0.0007**	**0.0001**	0.035	0.445	0.176	0.034	0.014
Reduction Potential (1)		0%	0%	0%	85%	0%	0%	0%	85%	0%
Average Benefit/Vehicle		0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0288	0.0000
Benefit for 40 Vehicles (kg)		**0.00**	**0.00**	**0.00**	**3.89**	**0.00**	**0.00**	**0.00**	**1,043.66**	**0.00**
Benefit for 40 Vehicles (Tons)		**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**1.15**	**0.00**

(1) Target reduction based on program goals

Diesel Retrofits, Clean Diesel and Alternative Fuels

Diesel vehicles have historically been a significant source of PM emissions and as such the EPA moved to lower the emissions of these vehicle classes several years ago. The mandating of ULSD for all on-road diesel fuel allowed for the universal adoption of emission devices that significantly reduced the PM and NO_X emissions associated with diesel vehicles. This was adopted with the 2008 model year and all on-road diesel engines after that date are effectively "clean diesel" as they were commonly referred to prior to the standard being implemented. Retrofits are only effective as a control measure in the short term. When older vehicles are retired their replacements will meet the new emissions criteria and no additional benefit will be realized.

Alternative fuels historically had inherent emissions benefits over conventional fuels; however it is not clear that this remains the case. Heavy duty diesel vehicle emissions standards encouraged the development of engine and exhaust control systems that dramatically lowered diesel emissions to levels originally thought difficult to achieve, while at the same time the state of the practice in alternative fuels (namely compressed/liquid natural gas, biodiesel, and propane) remained largely unchanged. The benefits of alternative fuels are no longer a certainty, and in recent work published for city buses[16] it was noted that alternative fuels do not show a demonstrable benefit over diesel buses built to current standards. Emissions standards for heavy duty engines are independent of fuel type, and the choice to use alternative fuel vehicles is generally driven by co-benefits outside of emission reductions such as the reduced cost of fuel. Compressed Natural Gas is increasingly being promoted as a cleaner fuel source; however the range of these vehicles tends

[16] Transportation Research Board. TCRP REPORT 146: Guidebook for Evaluating Fuel Choices for Post-2010 Transit Bus Procurements. March, 2011.

to be shorter and is not appropriate for long distance hauling. Liquid Natural Gas allows for an increase in range; however the limited number of refueling stations makes this a viable solution only in specific cases. Biodiesel and ethanol have lower energy densities than the fuels they replace which impacts mileage, however in general emissions are considered on par with similar, new diesel vehicles. No definitive work could be located verifying that a new, modern alternative fuel vehicle is any less polluting than a current model diesel vehicle, nor are there any indications that alternative fueled vehicles are now more polluting. It is recommended that replacement of an existing vehicle with an alternative fuel equivalent be analyzed as though the replacement was a modern, conventional (petroleum) fueled vehicle.

Hydrogen fueled and electric heavy duty vehicles were not considered a viable control measure due to the limitations of current technology. As the technology evolves these alternatives may warrant future consideration.

Calculations for Diesel Retrofits, Clean Diesel and Alternative Fuels

The EPA developed a "Retrofit Converter Tool" that may be used with the on-road retrofit strategy panel in MOVES that allows users to enter details about diesel trucks and buses that have installed emissions control equipment. Any retrofit projects must use the technology on EPA's Verification list[17]; however most regions only take credit for $PM_{2.5}$ and PM_{10} reductions as the verification for other pollutants has been questioned.[18] Care should be taken when calculating long term benefits for these projects, as retrofits only have a benefit over the remaining life of the vehicle. A five year impact is recommended in the CMAQ guidance, with retrofits only being appropriate to advance near term air quality goals and not as a long term measure.

An alternative to using the diesel retrofit calculator is to use MOVES emission rates for the pre-2007 model year vehicle (source) types. The list of verified retrofit technologies provided by the EPA gives percent reductions in emissions by pollutant and by device. MOVES can be used to generate an emission rate for a pre-2007 model year vehicle and the percent reduction applied directly to that rate. This also requires an estimate of the average annual vehicle mileage. As bus engines have been the focus of such programs, Table 4-4 below provides a list of Arizona transit agencies and an estimate of the revenue vehicles miles of travel per bus using data in the National Transit Database. Note this mileage does not include non-revenue "deadhead" mileage. This is typically assumed to be around 15 percent more mileage on top of the revenue mileage, or may be omitted if a more conservative value is preferred.

The impacts of engine replacement, early vehicle replacement and alternative fuels can be estimated using average emission rates for current model years or, conservatively, that of a current 2013 model year vehicle. These rates can be developed on a region by region basis using MOVES and available local data.

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[17] http://www.epa.gov/cleandiesel/verification/verif-list.htm
[18] An informal review found many programs specifically seek to reduce PM related emissions although it is common for HC and NO_X emissions to be reduced concurrently. As these co-benefits are not mandated or specifically enforceable, areas have opted not to take credit for them.

Table 4-4: Average Transit Vehicle Revenue Mileage

Agency	Bus			Demand Responsive		
	Revenue Vehicle Miles	Buses in Max. Service	Annual VMT/BUS (Miles)	Revenue Vehicle Miles	Buses in Max. Service	Annual VMT/BUS (Miles)
City of Glendale Transit	99,773	3	33,258	406,413	14	29,030
City of Phoenix Public Transit Department dba Valley Metro (Valley Metro)	16,914,563	427	39,613	3,733,691	117	31,912
Regional Public Transportation Authority, dba: Valley Metro (RPTA)	5,909,527	163	36,255	1,974,940	50	39,499
City of Scottsdale - Scottsdale Trolley (COS)	619,115	17	36,419	N/A	N/A	N/A
Surprise Dial-A-Ride Transit System (Surprise DAR)	N/A	N/A	N/A	84,859	7	12,123
City of Tempe Transit Division - dba Valley Metro (TIM - Tempe in Motion)	5,700,178	129	44,187	N/A	N/A	N/A
City of Tucson (COT)	7,985,511	200	39,928	3,332,883	115	28,982
Yuma Metropolitan Planning Organization (Yuma County Area Transit)	378,218	8	47,277	182,846	8	22,856

Source: 2011 National Transit Database

Using the values in Table 4-4, the equations used to determine the benefits of retrofits or engine replacements are:

Retrofits:
Daily Emission Reductions = (BEF) * EFF * ADT * 0.93 * 1 /1000 (kg/day)

Replacements:
Daily Emission Reductions = (BEF – AEF) * ADT * 0.93 * 1 /1000 (kg/day)

Where:

- ***BEF =*** The before emission factor for the current vehicles
- ***EFF =*** The effective reduction in the emissions for that specific pollutant as per the EPA verified list. In the case of VOC the HC reduction factor can be used[19]
- ***AEF =*** The after emission factor for the replacement vehicles
- ***ADT =*** The average daily mileage of the vehicles
- ***0.93 =*** The factor to convert from weekday to annual average daily traffic on arterials.

To generate annual emissions reductions, either substitute the average annual mileage (if known) or multiply the daily results by 250 days per year, which is equivalent to the number of weekdays per year (260) minus holidays per year (10).

Truck Stop Electrification/Auxiliary Power Units (APU)

During mandated rest periods, long distance truck drivers often remain in the cab of their vehicles if they are equipped for overnight stays. A trucker is likely to leave the engine running for cooling/heating and to provide power for appliances and accessories resulting in avoidable idling emissions. Some trucks are provisioned for "shore-side" power, similar to a recreational vehicle, which negates the need to run the engine while the driver rests. Another technology uses a device that inserts into a sleeve in an open window and provides climate control and additional services (electrical outlets, cable, internet access, etc.). Auxiliary Power Units (APUs) are a third idling alternative that provide air conditioning, heat, and power for sleeper cab appliances, as well as battery charging and start assist for the main engine while being less polluting than running the main engine. These devices can be diesel fueled, battery powered or a combination of both (FHWA, 2009).

To quantify the benefit of an anti-idling project, MOVES can be run to estimate extended idling emission factors for NO_X, PM_{10} and $PM_{2.5}$ for heavy duty diesel vehicles in the year of project implementation. The equipment must be installed within the air quality region in question. However, a correction factor may be applied to account for the times an APU is used outside the area. MOVES emission rates in grams per vehicle per hour are then multiplied by the estimated daily reduction in idling hours to determine the emissions benefits associated with truck stop electrification. For a project providing APUs, the benefit will be calculated as the difference between the idling emissions for diesel trucks before and after installation of the APUs.

[19] http://www.epa.gov/cleandiesel/verification/verif-list.htm

Calculation of the Benefits of Truck Stop Electrification/Auxiliary Power Units (APU)

In the absence of usage data, assume truckers are generally required to take a 10 hour break after 11 hours of driving. Therefore multiplying 10 hours by the number of spaces provides a coarse estimate of overall hours of idling reduced. If parking space utilization data is available for a particular location it should be used as the basis of the calculation. If estimates are used and are not based on survey data, a further reduction to account for uncertainty (developed in conjunction with EPA regional staff) may need to be employed.

Additional Significant Control Measures

Regional Diesel Anti-Idling Programs

Unnecessary diesel idling often occurs while vehicles wait at various terminals, buses wait outside schools, or commercial vehicles make deliveries. Attempting to restrict these and similar types of idling may have a significant impact on emissions, particularly $PM_{2.5}$ emissions. These programs commonly limit idling to no more than 5 minutes, and while most are focused on diesel vehicles some regions have expanded these programs to include all vehicle types. Enforcement is handled differently region by region and is a challenge in many locations as local police are often unable to dedicate additional resources to the effort. The number of vehicles at a single location does not need to be great to have a significant localized benefit. The MOVES hotspot guidance suggests that at levels as low as 10 heavy duty diesel vehicles idling on average is enough to be of air quality concern.[20]

The challenge in quantifying the benefits of these programs is that the amount of short term idling occurring (in excess of 5 minutes but less than a mandated 10-hour rest period) is not well understood. While idling emission rates can be obtained from MOVES, it is unclear what amount of time (the activity data for this measure) should be assigned. Such programs have obvious air quality benefits, however quantified benefits would be difficult to justify. In the research undertaken for this working paper, all the regions identified that had implemented these programs justified them qualitatively and did not calculate a specific air quality benefit.

Expanded or New Fuel Measures and Vehicle Inspection and Maintenance (I/M) Programs

In regions with significant air quality issues, reformulated fuel requirements and expanding vehicle I/M activities have the potential to generate substantial emissions benefits since these measures impact almost every vehicle within a region.

Calculating the benefits of such programs must be done within the context of MOVES and will impact how regional emissions inventories and/or conformity demonstrations are handled. As outlined in Working Paper 3, *Air Quality Conformity Procedures*, MOVES databases specify fuel formulation and fuel supply data based on available local volumetric fuel property information. For example, in the case of Reid Vapor Pressure (RVP),

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[20] USEPA. *Transportation Conformity Guidance for Quantitative Hot-spot Analyses in $PM_{2.5}$ and PM_{10} Nonattainment and Maintenance Areas.* December, 2010

the default value should be changed to reflect the regulatory requirements and differences between ethanol- and non-ethanol blended gasoline. Agencies should coordinate with EPA to change their fuel and/or I/M programs and to incorporate appropriate assumptions for future analysis years into their MOVES modeling protocols. Legislation must be in place to ensure the requirements are enforceable before credit can be taken.

When calculating the benefit of other control measures, any expanded fuel reformulation and/or I/M program must be analyzed first. Implementation of these measures will reduce the emission rates for entire vehicle classes. As a result, the incremental benefit for other control measures that reduce trips or improve vehicle operations will decrease.

Trip Reduction Measures

The MAG *Methodologies for Evaluating Congestion Mitigation and Air Quality Improvement Projects* is recognized nationally as a well-developed analysis framework for the project types it covers. The TCMs analyses below are based on the methods found in the MAG CMAQ guidance, and were altered to remove any weighting factors developed to assist MAG in rating and ranking projects. Note that because generic emission rates are not available for Arizona, the following describe only the methods for calculating the transportation impacts.

Bicycle and Pedestrian Facilities

Bicycle and pedestrian facilities can help encourage the use of "active transportation" modes to supplant local, short distance commuter and other personal trips. The improvements should not be focused on recreational facilities as these are unlikely to off-set auto trips. Also note that the benefits calculated here are focused on tailpipe emissions and not re-entrained dust (covered earlier in this working paper).

The estimated number of vehicle trips replaced by bicycle or pedestrian trips is based on a number of factors. The ADT on the adjacent or nearest parallel arterial to the proposed bicycle or pedestrian facility is a basic input. The maximum allowable ADT is 30,000 vehicle trips per weekday for this approach to be valid. Weekday ADT can be converted to annual average daily traffic (AADT) by multiplying by a conversion factor of 0.93. The vehicle trips reduced will be calculated by multiplying the AADT by the sum of the adjustment factor (A) found in Table 4- 5 and the activity center credit (C) found in Table 4- **6**. The adjustment factor (A) is dependent upon the length of the bicycle/pedestrian project and the AADT as well. Given the relative importance of bridges and underpasses that connect bicycle/pedestrian paths, the adjustment factor used for bridges and underpasses should be based on the sum of the lengths of the two paths connected. Usage estimates for bicycle/pedestrian facilities can also benefit from credit (C) for the number of activity centers near the proposed facility.

Table 4- 5: Adjustment Factors[21]

ANNUAL AVERAGE DAILY TRAFFIC (AADT)	LENGTH OF PROJECT (one direction)	**ADJUSTMENT FACTOR (*A*)**
AADT ≤ 12,000 vehicles per day	≤ 1 mile	0.0019
	> 1 mile and ≤ 2 miles	0.0029
	> 2 miles	0.0038
12,000 < AADT≤ 24,000 vehicles per day	≤ 1 mile	0.0014
	> 1 mile and ≤ 2 miles	0.0020
	> 2 miles	0.0027
AADT > 24,000 vehicles per day	≤ 1 mile	0.0010
	> 1 mile and ≤ 2 miles	0.0014
	> 2 miles	0.0019

Table 4- **6 : Activity Center Credits**[22]

Examples of Activity Centers: bank, church, hospital, health care facility, park and ride lot, office park, post office, public library, shopping area or grocery store, schools, university or junior college.		
Number of activity centers	**ACTIVITY CENTER CREDIT (*C*)**	
	Within ½ mile	Within ¼ mile
at least three	0.0005	0.001
more than three but less than seven	0.001	0.002
seven or more	0.0015	0.003

The VMT reduced by bicycle/pedestrian facilities is estimated by multiplying the vehicles reduced by the average trip length. Consistent with assumptions in MAG transportation modeling concerning pedestrian trips to transit centers, a pedestrian trip length of one-half mile will be assumed. Based on data in the Bicycle Demand and Benefit Model (Alta Transportation Consulting, 2000), an average bicycle trip length of four miles will be assumed. For multi-use paths, it will be assumed that half of the trips are bicycle and half are pedestrian. Therefore, an average trip length of 2.25 miles will be applied for multi-use paths.

Calculations of the Potential Impacts of Bicycle and Pedestrian Facilities

Vehicle Trips Reduced (VR) = AADT * (A + C)
Vehicle Miles of Travel Reduced (VMTR) = VR * Trip Length

[21] Adapted from CARB, 2005
[22] Adapted from CARB, 2005

Where

- ***A*** = The adjustment factor from Table 4- 5
- ***C*** = The activity center credit from Table 4- **6**
- ***AADT*** = The average daily traffic on the adjacent or nearest parallel arterial (Maximum 30,000) multiplied by 0.93

The VMTR value can then be multiplied by emissions rates in grams/mile developed from MOVES runs for the specific region in question. If per trip vehicle starting emissions are available those values can be multiplied by the VR value to account for this additional reduction.

New Bus Service

Bus service on new routes and increased frequency on existing bus routes reduce vehicle trips and VMT. The daily emissions reduction attributable to new bus service can be estimated based on the difference between the emissions from the light duty vehicles replaced by the bus service and the sum of the bus emissions from the new service. Vehicle emissions resulting from people driving to access the bus will also be accounted for.

Existing transit models in the region should be investigated for the ability to estimate the impact of new bus routes prior to using the following methodology. If the regional travel demand model is capable of modeling the impact of transit improvements than it should be used as the preferred tool for determining emissions credit. The methodology presented here is intended for small routes that a regional travel demand model might be insensitive to, or for isolated routes in a region not currently modeled.

The vehicle miles of travel replaced (VMT_{REP}) by the new bus service is estimated based on the fraction of riders on the bus who drove to their destination prior to introduction of the new bus service (F_1). This fraction will be multiplied by total bus riders and the average trip length replaced by the bus service (Trip $Length_1$). The VMT replaced by bus trips will be multiplied by on-road light duty vehicle emission factors from MOVES.

The Vehicle Trips Reduced (VR) by the new bus service will be estimated as the number of riders who previously drove to their destination minus the number of riders that drove to the bus. The vehicles reduced will be multiplied by the off-network light duty vehicle emission factors per vehicle per hour from MOVES.

Calculation of the Impact for New Bus Service

VMT Replaced (VMT_{REP}) = $R * F_1 * trip\ length_1$
VMT Added (VMT_{ADD}) = $R * F_2 * trip\ length_2$
Vehicles Trips Reduced (VR) = $R * (F_1 – F_2)$

Where:

- ***R*** = The average ridership on the bus per operating day
  For example, if the new bus is expected to carry 400 passengers per day, *R* would equal 400. Default = 284 (Based on 2011 RPTA data).
- ***F_1*** = The fraction of riders on the bus who previously drove a single occupant vehicle
  For example, if 75 of 100 bus riders would have driven an SOV to their destination, F_1 would equal 0.75. Default = 0.50 (CARB, 2005).

- ***Trip length$_1$* =** The average trip length replaced for each rider who previously drove
  Default = 10.6 miles (from 2001 Maricopa Regional Household Travel Survey and 2002 transportation model validation, Feb.15, 2005).
- ***F_2* =** The fraction of riders who drive to transit
  For example, if 5 of 100 riders of the new bus drive to reach the bus, F_2 would equal 0.05. Default = 0.03 (RPTA, 2008).
- ***Trip length$_2$* =** The average trip length driven to transit
  Default = 5 miles (Valley Metro, 2001).

The (VMT Replaced – VMT Added) can then be multiplied by emissions rates developed from MOVES runs for the specific region in question. If off-network (starting) emission rates are also available those can be multiplied by the [R x (F_2-F_1)] value to get an additional reduction. The VMT for the bus should be calculated using available route and schedule data, which can be further adjusted by multiplying by a factor to account for non-revenue mileage (1.15 is a commonly used value, but local data should be used if available). The bus mileage can be multiplied by appropriate emission rates for the region and subtracted from the overall benefit of the project.

Park and Ride Facilities

Park and ride facilities reduce light duty vehicle trips and emissions by encouraging carpooling, vanpooling, and transit ridership.

This methodology is based on the number of park and ride spaces and the projected utilization rate. It assumes that each vehicle parked in the facility (spaces times the utilization rate) represents two commute trips. The average trip length for commute trips is derived from regional commuting data collected by the Maricopa County Trip Reduction Program. The average trip length driven to park and ride lots (derived from a MAG park and ride lot survey) is subtracted from the average commute trip length. The net trip length is applied to the total commute trips reduced to obtain the average weekday reduction in VMT.

Calculation of the Impacts of Park and Ride Facilities:

VMT Reduced (VMTR) = S * U * 2 * (15.4 – 3.5)

Where

- ***S* =** Number of parking Spaces provided in the park and ride facility
- ***U* =** Average weekday utilization rate
- ***2* =** Number of vehicle commute trips per average weekday
- ***15.4* =** Average commuter trip length by all modes (MCAQD, 2009)
- ***3.5* =** Average miles driven to park and ride lots

The VMTR value can then be multiplied by emissions rates developed from MOVES runs for the specific region in question.

Trip Reduction Programs/Measures

Travel Demand Management (TDM), Transportation Management Associations (TMA), trip reduction programs and similar activities promote and facilitate efforts to help alleviate peak period congestion. These programs are challenging to quantify for a number of reasons. Many programs use overall mode share as a measure of their impact, for example a TMA may set a goal for a certain percent of all trips to be diverted from the drive-alone mode and use ongoing surveys to verify their effectiveness. This allows for flexibility to implement the most effective regional programs and allows the programs to evolve over time.

One recommended tool to analyze these programs is the EPA COMMUTER Model[23]. The COMMUTER Model has not been updated with MOVES emission rates. Agencies may wish to use the COMMUTER Model to calculate total VMT and vehicle trips reduced, and then apply locally-developed MOVES emission rates. Agencies may also wish to bundle the TMA efforts with other voluntary measures which would restrict the maximum impact to 3 percent of the overall emissions inventory.

Traffic Flow Improvements

Traffic Signal Coordination and Intelligent Transportation Systems

At this time there is some question on how to use the MOVES model to analyze control measures that improve vehicular traffic flow. Traditionally, simulation methods were used to estimate the reduction in vehicle delay, which were assumed to be idling emissions (in whole or in part), and that value was multiplied by an idling emission rate. MOVES fundamentally changes the way in which these projects should be reviewed; unfortunately, guidance is not available at this time to leverage these capabilities in the model. During this time of transition agencies may wish to use other tools, omit these projects for credit all together, or work with the regional EPA office to develop a sensible approach to quantifying the benefits that can be expected.

Land Ports of Entry Operational Improvements

The Border Crossings/Land Ports of Entry (LPOE) between the US and Mexico are a known source of emissions. The flow of freight traffic between the US and Mexico ensures high volumes, and the delays due to excessive congestion and additional inspection procedures results in significant amounts of localized vehicle emissions. Streamlining LPOE operations in order to improve local air quality was identified as a goal in the Border 2020: U.S.-Mexico Environmental Program[24]; elements of which have already been implemented under the Department of Homeland Security's US-VISIT program. Analysis of the air quality impacts of LPOE operations is very complex and requires traffic micro-simulation. Such an air quality analysis was completed under the US-VISIT program and may be available by request. If these studies are unavailable, agencies should seek assistance from regional EPA representatives on appropriate background emissions assumptions. Given the lack of local or state control over the operation of these facilities they are unlikely to be suitable candidates for inclusion as a specific, local control measure.

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[23] http://www.epa.gov/OMS/stateresources/policy/pag_transp.htm
[24] http://www2.epa.gov/border2020/borderwide-publications